Chapter

Impact of Climate Change on Sugarcane Cultivation

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Abstract

Sugarcane is one of the most important cash crops grown in India and occupies the second position after Brazil. The changing climatic condition affects sugarcane cultivation in many directions. Sunscald, frost injury, and chlorosis are the prominent results of adverse climatic conditions like high temperatures or extreme low temperatures. This article depicts the influence of climatic change on sugarcane cultivation as well as the probable mechanism that plants take up to cope with the changing scenario.

Keywords: frost injury, high temperature, sugar recovery, sunscald, chlorosis

1. Introduction

Sugarcane (*Saccharum officinarum* L.), a member of the grass family (Poaceae) and class Monocotyledones, is an economically important crop grown in almost all tropical and sub-tropical countries spread across the world. Commercial breeds of sugarcane are derived from crosses of *S. officinarum* and *S. spontaneum*. *S. officinarum* is known as noble cane bear chromosome no. 2n = 80 [1]. This crop can be projected as the crop for the future owing to its capacity not only to produce sugar but also a renewable source of energy in the form of ethanol, electricity, and many biobased products. Sugarcane is one of the important cash crops grown in India. Uttar Pradesh is the sugar bowl of India followed by Maharashtra and Karnataka together produce around 80% of the sugarcane in India that helps to attain the second largest producer country of sugar after Brazil. However, the Government of India had claimed that India would be the largest producer of sugarcane in 2022–2023. Nearly 2.8 lakh farmers have been cultivating sugarcane in an area of 3.93 million ha with annual production of 170 million tones with productivity around 67 t/ha (indiaagronet.com). The crop is presently cultivating across the states of India having diverse agro-climatic conditions contributing to the national GDP is 1.1% [2]. Sugarcane is cultivated broadly in two agroclimatic zones viz. tropical and sub-tropical regions where the Tropical region contributes about 45%-55% and subtropical region contributes 55%–45% However, sugarcane is cultivated in five different agro-climatic zines throughout India viz., North Western, North Central, North Eastern, Peninsular and Coastal zones.

Sugarcane is a water-loving plant. It demands sufficient water particularly during the active vegetative growth stage. Lack of sufficient water results in poor yield and lower sucrose recovery. Likewise, it requires an optimum temperature for proper growth and development. Inadequacy of any one of the physiological parameters can hinder growth and development of the crop which leads to poor economic yield and less sucrose recovery. So, adequate moisture as well as temperature is required to obtain proper yield.

2. Climatic requirements for sugarcane

2.1 Temperature

Temperature requirement is varied according to the different critical stages of sugarcane, viz. germination, tillering stage, early growth stage, active growth and elongation or maturation stage. Each of these stages has a different temperature requirement. For example, optimum temperature requirement for bud sprouting or germination is 32–38°C. But, germination slows down below 25°C. But, the temperature above 38°C increases respiration and thereby reduces photosynthesis. In contrast, relatively low temperatures in the range of 12–14°C is desirable in the ripening stage to accumulate more sugar [3].

2.2 Water requirement

The soil must have sufficient water during germination. Depending upon the type of soil, agro-climatic zones, and method of planting material used, water requirement varies. To produce 1 ton of cane on average 60–70 tons of water is needed. The crop should be irrigated immediately while the available moisture content reaches 50% level. In tropical India, total water requirement is varying from 2000 to 3000 mm for optimum growth of cane. Whereas, in sub-tropical India, the water requirement is 1400–1800 mm during the crop growth, and for *adsali* crop the requirement of water is 3200–3500 mm (NFSM.gov.in).

Sugarcane cultivation in tropical area required frequent irrigation. During germination, i.e., 1–35 days after planting irrigation is required in every 7 days interval. In the next stage, i.e., in tillering stage or 36–100 days after planting, irrigation should be applied once in 10 days interval. When the crop attains grand growth stage, i.e., 101–270 days after planting, irrigation should be applied once in 7-day interval, and at the end of the crop stage or 271 days after planting, water requirement is gradually reduced. So, one irrigation at 15 days interval is sufficient adjusting to the rainfall pattern.

2.3 Humidity

Nearly 80–85% relative humidity (RH) is required for cane elongation during grand growth stage. RH above 40% coupled with warm weather favors vegetative growth of cane, and 45–65% relative humidity coupled with limited water supply is favorable during the ripening phase. Broadly two different sets of climatic requirements are necessary to complete the life cycle of the plant. One is bright sunshine hours in the warm season for a long duration with high humidity and optimum rainfall in the growing season while the ripening season needs the least precipitation, dry weather with relative humidity of about 51% [4].

2.4 Sunshine

Sugarcane is a sunshine loving plant. Greater the incidence of radiation, higher is the sugar recovery. Bright sunshine hours of approximately 7–9 hours are essential for both growth and ripening stages [4]. Bright sunshine hours accelerate photosynthesis and this ultimately leads to increase sugarcane yield. Cloudy weather reduces the number of tillers while the bright sunshine hours for 7–9 hours is essential for maximum tillering, grand growth as well as maximum stalk formation [4].

3. Favorable conditions for maximum sugar recovery

Dry weather with low humidity, maximum bright sunshine, and cooler night with wide diurnal variation accompanied by little or no rainfall during ripening period is required for maximum sugar recovery. These conditions favor high sugar accumulation. Adverse climatic conditions like very high temperature or very low temperature deteriorate the juice quality, thus affecting the sugar quality. Hot and humid condition also favors disease and pest infestation which ultimately affect juice quality and sugar recovery (Directorate of sugarcane development, Govt. of India, Lucknow, 2013).

4. Effect of climate change in sugarcane crop

Climate change can have significant impact on sugarcane production in the world (as shown in **Figure 1**) especially in the developing countries due to non-availability of suitable cultivar to withstand natural hazards like drought, wind and frost injury, and high temperature. Poor forecasting systems and mitigating strategies also add difficulties to mitigate the situation [5].

4.1 Erratic rainfall

Erratic rainfall leads to drought-like situation is considered as most important stress factor for sugarcane cultivation. As mentioned earlier, water requirement is varied according to stages of the crop, and changes in plant physiology due to water stress were noticed by the different researchers. Domaingue [6] stated that the number of internodes is reduced if water deficit increases. Misra et al. [7] also observed that 43.51% reduction in the number of internodes in drought-affected canes. Jones et al. [8] clearly mentioned about the reduction in the crop biomass production up to 35% under water stress condition.

High temperature also leads to increase the evapotranspiration rates that reduce the amount of water available in soils, making the planting of sugarcane increasingly difficult and newly planted crop demand more irrigation.

Crop suffers from drought in early and mid-growth stage results in low sucrose yield. On the country, moderate drought in late growth stage can improve sucrose content.

A study carried by Endres et al. [9] by exposing six sugarcane varieties at different growth stages, viz. tillering stage, stalk elongation, grand growth stage, and ripening stage to drought. He recorded a reduction in leaf length and leaf width especially in the stalk elongation and grand growth stages. Misra et al. [7] also observed similar

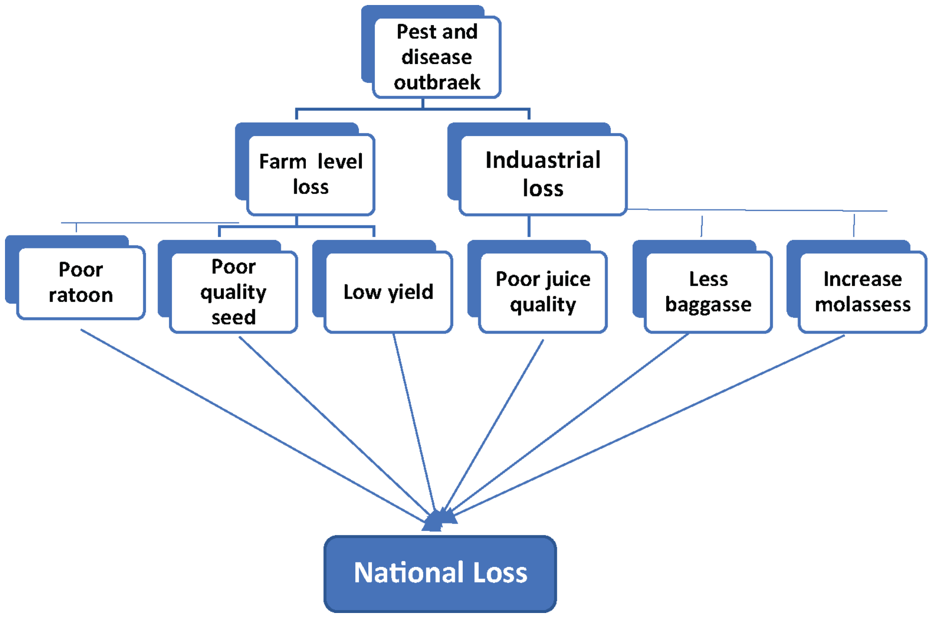

Figure 1.
National losses due to pest and disease outbark (concept: Sadam Hussain, climate change and agriculture, Intech Open).

results, wherein leaf width decreased by about 31.11% in drought-affected sugarcane compared to sugarcanes grown under normal conditions.

Crop root is the first part that detects water deficit in the root rhizosphere and sending signals to other parts of the plant [10]. The closing of the stomata is one of the response mechanisms of plants to minimize further water loss.

Zhao et al. [11] observed that water stress reduced the number of large tillers (>20 cm) but increased the number of small tillers. It was also reported that the roots were found in the top (0–30 cm) as well as middle soil layer (30–60 cm) for canes grown in irrigated condition whereas root length was found below the 30 cm soil layer in drought-treated plants grown in rhizoboxes [12].

4.2 Effect of high temperature

Extreme high temperature affects plant system in many ways (**Figure 2**) from the seed germination to yield characters all are affected by rise in temperature. It is well established that the optimum range of temperature varies for different stages of sugarcane crop. For example, the optimum temperature required for germination (sprouting) of cane sett is between 28 and 32°C. Temperature above 38°C reduces the germination and also affects the vegetative growth by reducing photosynthetic rates and increasing the respiration [4].

Although the tillering capacity of sugarcane mainly governed by genetic factors, temperature fluctuation may also affect numbers of tillers produced by a particular variety.

During ripening period temperature requirement is low, i.e., 12–14°C due to which sucrose accumulation is more.

Fageria et al. [13] and Clements [14] reported that sucrose accumulation is optimum within the temperature range of 12–14°C but it declines gradually above 26.6°C.

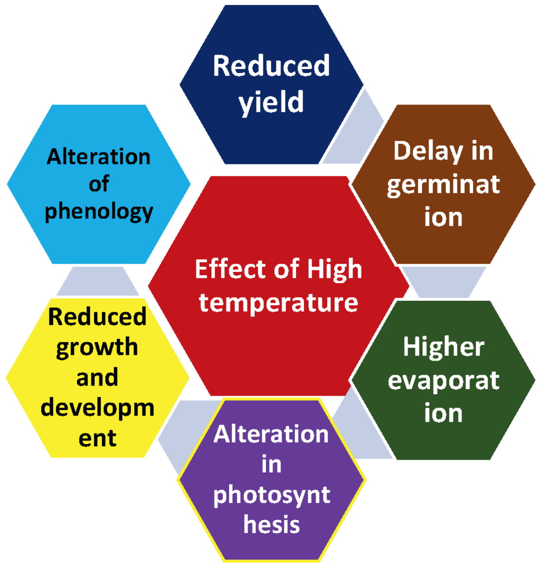

Figure 2.
Effect of high temperature.

This is also supported by the findings of Binbol et al. [15] and Gawander [16]. They observed that at high temperature sucrose is converted into fructose and glucose and enhances abiotic diseases.

4.3 Frost

Sever cold weather inhibits bud sprouting in ratoons and arrest cane growth. At temperature 1–2°C leaves and meristem tissues may be killed.

5. Mechanism to counteract adverse climatic conditions

5.1 Changes in plant internal machinery to cope up high temperature

Like the human and animal, plants can also sense increase or decrease in ambient temperature by using a complicated set of sensors that are located in various cellular compartments. Plants try to counteract heat effect by producing osmolytes and antioxidants [17]. Farooq et al. [18] reported that proline, glycine betaine, and soluble sugars are deposited more in heat-affected plant to protect the cellular damage. Chlorophyll present in the thylakoid membrane of chloroplast harvest light energy and transform into energy that plants utilizes to various function. Under normal growth condition, synthesis of chlorophyll is equilibrium , But under stress conditions, level of chlorophyll content decreases leading to chlorosis [19]. Exposure to high-temperature chloroplast are unfolded and proteolytic enzyme degradation of chloroplast may occur [20].

Rise in temperature compels the sugarcane crop to some changes in their internal cellular morphology. It was recorded by Bita and Gerats [17] that the rising temperature up to 35°C and above causes injuries to cell membrane, disruption of cell membrane permeability, and microtubules organization and also affects elongation and expansion of the plant. High temperature also generates dangerous oxygen species and affects sucrose quality and sugar extraction. Sucrose phosphate synthase (SPS) and sucrose phosphate phosphatase (SPP)—these two enzymes are required for sucrose synthesis, and it was reported that both these enzymes are affected by change in temperature [21]. Chloroplast serves as the key component for metabolic centers and plays key role in sensing heat stress. CO_2 assimilation, thylakoid membrane fluidity, electron transport, and photochemical reactions are the major areas that is affected by heat stress. To respond heat stress, heat-shocked proteins (HSP) are evolved in sugarcane plants. The heat shocked transcriptome factor (HSTF) regulates the expression of Heat Shocked Protein Gene. Researchers are going on the function of HSP and HSTF that regulates the response system to heat stress in plants.

5.2 Mechanism to cope up with drought

Sugarcane crop has diverse adaptive traits to cope up with water stress conditions. Since sugarcane is a water-loving plant, a deficit of water could lead to poor cane yield. So, drought-tolerant sugarcane varieties have minimum transpiration rate with maximum stomatal diffusive resistance [22]. This trait ensures the conservation of water in the plant system during stress conditions.

Reduction in stomatal conductance is another important aspect identified as the immediate response during drought conditions to conserve moisture in the system through decreased transpiration rate [9]. Plant water potential is directly correlated with stomatal conductance and leaf water turgor, thus limiting stomatal opening and significantly reducing gas exchange and subsequently photosynthetic rates [23]. Relative water content (RWC) is an important parameter to easily distinguish drought-tolerant and drought-susceptible varieties. A study conducted by Dapanage and Bhat [24] showed that RWC value was higher in irrigated crops as compared to plants grown in non-irrigated conditions.

6. Effect of climate change in plant pathogen and insect pest

Sugarcane is a long duration crop. It takes about 12–18 months to mature depending on variety. On the basis of sowing time, it is known as *Adsali* (June–August) or 18 months crop and *Eksali* (December–February) or 12 months crop. After harvesting also, generally, 2–6 ratoons are followed in Indian conditions. Therefore, the crop experiences varying temperature and humidity throughout its life span. Fluctuation of temperature and humidity invites many pest and pathogen to attack the crop.

Disease-causing pathogen propagules like spore and spore survival, spore germination, host penetration, growth within the host, sporulation, and ultimately dispersal—all are affected by abiotic conditions such as temperature, moisture, light, wind, and nutrient.

Herbivore arthropods like sugarcane borer, stalk borer, and Mexican borer can cause significant crop loss in abiotic stressed crops due to drought. The fecundity of *Eoreuma loftini*—the Mexican rice moth is positively correlated with increases in drought as the drought prevails, the number of dry leaf availability for egg laying increases. Showler and Castro [25] observed that under irrigated conditions 82.8–90.2% less egg in of *E. liftini* was reported than non-irrigated drought-affected crop.

Increased pest and disease infestation is recorded due to the abrupt weather changes. Incidence of smut disease (*Sporisorium scitamineum* (Syd.) is increasing due to rise in temperature [26], and it was also found that the disease was more severe on sandy soils than on organic soils because of high temperature and relatively dry conditions.

Likewise, the prolific dry weather aggravates the symptoms of ratoon stunting disease. On the other hand, severe storms and hurricanes can spread leaf scald, caused by *Xanthomonas albilineans* [27].

Most of the sugarcane diseases appeared in severe form from time to time depending on the prevalence of suitable climatic conditions for pathogen attack. For example, sugarcane orange rust disease in Florida was much severe in the 2012 and 2013 growing seasons than other years due to warmer winter and higher humidity [5].

The severity of rust disease is associated with winter temperature and sufficient relative humidity. Sugarcane orange rust in 2012 and 2013 in South Florida was the most severe one since its first record in 2007 [28]. Warmer winter and high humidity is the crucial for the rust spores surviving and fast development [29], which was prevalent in that endemic areas.

A survey report conducted by Florida sugarcane industry reported that sugarcane growers used fungicides to manage rusts, but it was found that the cost of application of fungicides in three split doses per hectare was found to be equivalent to the loss of three tones of cane yield/ ha costing around $63 million in terms of monitory return in 2013.

In India also, the fluctuation of temperature has increased rust incidence during the past few years. Dattaray Jondhale, a sugarcane farmer of Herwad village in Kolhapur district of Maharashtra, explained his experiences to Indian Climate Dialog in 2019 that the rust disease of sugarcane occurred as numerous lesions on individual leaves giving it brown or rusty appearance. That leads to the premature death of the leaf, reducing the number of active leaf per plant, the number of stalks per plant, and length of stalk drastically reduced in susceptible varieties.

In such cases, the number of live leaves per plant is seriously reduced, while in very susceptible varieties there may be fewer stalks and reduced diameter and length of the stalks. It was also reported that rust is more severe in the young stages of the plant than declining with increasing crop age. A mild winter will likely allow rust to survive for a long time and re-emerge as a problem.

7. Physiological disorders of sugarcane due to changing climatic conditions

Environmental or physiological stresses cause immense quantity and quality loss of this crop worldwide. Some of the physiological disorders commonly observed in affected cane fields are discussed below.

7.1 Banded or cold chlorosis

This type of physiological disorder occurs due to high or low temperature. Waraitch and Kanwar (1977) first reported banded chlorosis in sugarcane clone S-98/70 of Punjab due to the severity of low temperature (minimum 0.50C). Later on 2011, banded chlorosis has been noticed in Maharashtra, India during 2nd week of March when the minimum temperature was recorded within the range from 10-12°C during December-January in the most popular tropical varieties Co 86032 and CoC 671 (Web report of VSI, Pune). The same condition has also been reported in 2019 when the minimum temperature remained below 5°C during December- January

[30]. Tissue chlorosis extends the both sides of the midrib of the leaf followed by leaf discoloration from yellow–green to white. Chlorotic bands may be visible near the base of the older leaves toward the tip of the leaf.

7.2 Sunburn or sunscald

Two types of sunburn can be generally observed in the affected field. They are leaf scorch that affects the foliage and sunscald that affects the bark. Drying of leaf lamina initially on the leaf apex of newly unfurled leaf and then progressed toward the middle of leaf lamina. Injured leaf used to dry within 2–3 days from leaf apex to bottom. Here, the injured leaves did not regain and the injury was irreversible.

7.3 Frost injury

Frost-injured plant cells are generally dehydrated as the ice crystals are formed in tissues of the plant that are usually filled with water. This results in distortion of the cell membrane followed by the collapse of plant parts. Frost-injured sugarcane crop develops water-soaked areas with light brown discoloration of tissue, and on splitting open the frost-injured plant, water-soaked areas developed with light brown discoloration of tissue, and the growing point may turn black resulting in hollow stalk on maturity. The emergence of side shoots from the top two to three eyes is one of the characteristics of frost-affected canes.

8. Strategies to mitigate adverse climatic condition

Diverse technology can be adopted to mitigate adverse climatic conditions. Planting stress-tolerant varieties is the first and foremost criteria to be considered while thinking for mitigating adverse climatic condition. As mentioned earlier, critical need of water at different stages of the cane growth is the pre-requisite to harvest a good return. So, improving irrigation facility with high efficiency and with proper drainage facility is the utmost need.

Incorporation of clonal propagation or tissue culture, molecular biology, and gene transformation technologies to improve breeding and selection efficiencies and to introduce desirable genes of interest carrying improved agronomic trait [31] so that the breeders and scientist could come up with new sugarcane cultivars that can be easily fitted to climate change.

Genetically modified (GM) sugarcane varieties such as glyphosate resistance, disease and pest resistance, water stress tolerant, high sucrose content were developed to mitigate adverse climatic condition. Budeguer et al., in 2021 [32] mentioned about the genetic transformation of sugarcane crops. In his study, it was mentioned that Brown and Birch in 1992 described the development of herbicide-resistant genotypes by microprojectile bombardment of selected genes and incorporation in suitable varieties to produce sugarcane crop with selected traits ot transgenic sugarcane with desirable traits. This was followed by development of glufosinate resistant sugarcane genotypes by Agrobacterium mediated gene transfer technology, So, in general both Agrobacterium mediated or biolistic method are successfully used in development of transgenic sugarcane cultivars.

Studies by Zhou and Li [31] indicated that on treating seed cane by ethephon-ethylene-producing substances at low concentration increases drought tolerance of cane.

They also reported that foliar application of ethephon reduced cell membrane injury caused by water stress, thereby increasing water potential in leaf tissue. Cell protective enzymes such as peroxidase and polyphenol oxidase activities are also enhanced.

Weather forcasting during the cultivation period is utmost necessary for the farming community to earn a good harvest from their field. For this, scientific use of Artificial Intelligence and Machine Learning (AIML) should be popularized amongst the farming community.

Breeders can apply information technology (IT) to develop computer database system incorporating growth and physiological traits of different cultivar to identify elite clones having tolerance or resistance mechanism to biotic or abiotic stress [33].

Last but not least, the combination of basic breeding techniques, physiological screening of improved trait, and new technologies of molecular biology and biotechnology can mitigate the negative effect of climate change and improve sugarcane yields, productivity, and sustainability [34–36].

9. Conclusion

The sugarcane industry is not only concentrating on sugar and jaggery production but is gradually transformed into a bio-based industry that will produce electricity, bio-ethanol, bio-manure, and bio-chemicals that open up more research wings to be a profitable agribusiness agriprenurship development which ultimately makes economic upliftment of developing countries. Therefore, it is an urgent need to focus more research on the development of stress-tolerant sugarcane verities in the present-day situation of global climate change.

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